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N.I. Johansen, P.C. Chalich and E.W. Wellen

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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The U.S. Army Cold Regions Research and Engineering Laboratory's permafrost tunnel at Fox, near Fairbanks, Alaska, was used to investigate the sublimation process in permafrost silt. The rate of increase in thickness of the dried silt layer from sublimation was found to be approximately 0.023 in. (0.058 cm) in 1 month and closely related to the relative humidity in the tunnel. Sublimation prevention studies consisted of evaluation of various membranes to impede the sublimation. Ice was found to show promise as an easily installed, effective membrane when applied as a fine water mist and subsequently left to freeze.

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PREFACE

This report was prepared by Dr. N.I. Johansen, Associate Professor of Geological Engineering, University of Alaska, and P.C. Chalich and E.W. Wellen, graduate students at the University of Alaska.

Funding for the students' research was provided by the U.S. Department of Interior, Office of Surface Mining. In-kind support and access to the CRREL Permafrost Tunnel were provided by the Alaskan Projects Office of the U.S. Army Cold Regions Research and Engineering Laboratory. Dr. Johansen's research was funded by the University of Alaska.

This report was technically reviewed by Drs. G.K. Swinzow and T.T. McFadden of CRREL.

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SUBLIMATION AND ITS CONTROL IN THE CRREL PERMAFROST TUNNEL

N.I. Johansen, P.C. Chalich and E.W. Wellen

INTRODUCTION

In the CRREL Permafrost Tunnel (Fig. 1 and 2) sublimation is extremely apparent, but because of the tunnel's limited usage it poses no significant problems. However, in an operating mine with forced air ventilation and continuously operating machinery, the problems associated with sublimation might no longer be insignificant. The dust released as a result of the sublimation process poses not only an obvious respiratory threat, but an additional safety threat, as fine silt suspended in the air reduces visibility.

THE SUBLIMATION PROCESS

An understanding of sublimation and its causes is needed before one can develop methods for handling problems originating from this process. Sublimation is simply the process of ice evaporating directly into vapor without passing through the liquid phase. In order for sublimation to occur there must be enough "room" between air molecules to allow the water molecules to enter the air. In other words, the relative humidity of the air must be below 100%. As far as the permafrost is concerned, there is liquid water and ice present. But, for the purpose of this investigation, we were looking at the drying of the soil resulting from the sublimation process. Water content determination included liquid water as well as ice.

The air in an enclosed space, such as the CRREL tunnel, will in time accept all the water it has room for. After that point it may exchange water with the surfaces it comes in contact with, but it cannot accept any greater amount because saturation has occurred. If the sublimation does not stop, either the air is somehow losing moisture or the natural or forced ventilation mixes the tunnel air with unsaturated air from the outside.

During the winter months when the outdoor temperature is below that of the tunnel, the tunnel ventilation panels and shaft are opened to allow the cold winter air to enter and cool the tunnel's permafrost surface. The effects of this winter cooling plus summertime refrigeration act together to maintain the existing thermal regime. The outside air in the winter has a very low specific humidity and therefore picks up moisture quite readily as it warms and passes through the tunnel. Between the process of sublimation and the process of air exchange, the wintertime relative humidity balances out at around 64%. In the summer months when the tunnel portal and ventilation shaft are closed, the relative humidity inside the tunnel should rise to 100%; however, it actually drops to around 55% (Wellen 1979). This unexpected drop in relative humidity was found to be caused by the refrigeration system which removed between 8 and 12 gal (30 and 45 L)

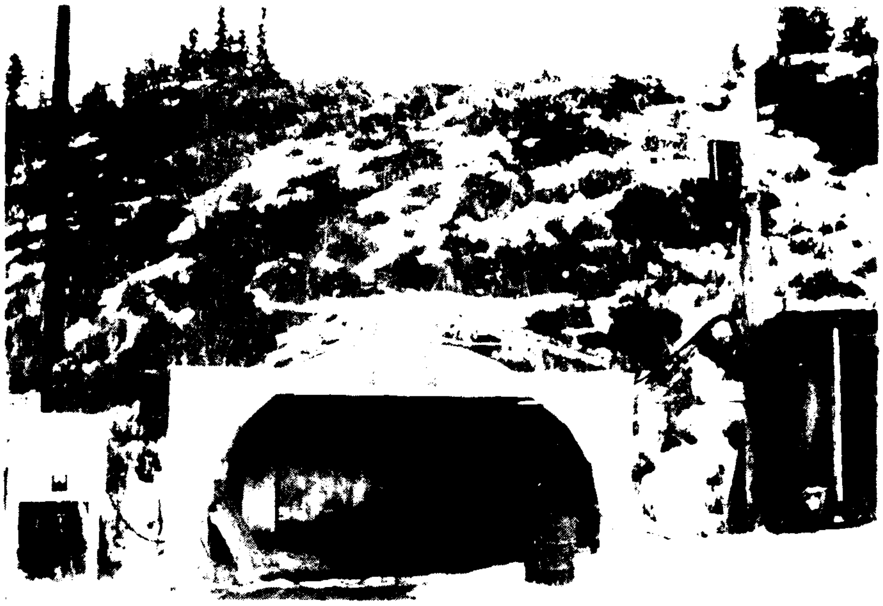

Figure 1. Portal of CRREL permafrost tunnel, near Fox, Alaska.

Figure 2. View of main adit.

of water daily. Wellen observed a sublimation rate of approximately 0.023 in. (0.058 cm) per month (Wellen 1979) but with variations from varying moisture content at the individual sites.

Under working conditions during mining, the heat liberated by machinery, personnel, and ventilation would require a larger refrigeration output. This increase in refrigeration effort would in turn increase the rate of air moisture removed and hence sublimation of the ice in the soil, making sublimation control all the more important.

Thickness measurements of the dry soil layer resulting from sublimation were made at several places in the tunnel in order to establish the rates given above. Sites where the original tunnel wall was intact and sites where the sublimated layer was removed to expose a fresh surface were both used. Wellen also made measurements of air velocities and humidity in the tunnel (Wellen 1979).

Wellen (1979) further found that the grain size of the material undergoing sublimation does not, conclusively, have a large effect on the sublimation rate. A difference is apparent in that the sand will continuously slough off whereas the silt stays in place and a layer of dehydrated material accumulates. The silt is possibly held together by slight amounts of salts (such as calcium carbonates) left behind after most of the soil moisture is gone. The moisture content of this "dust" was measured to be about 5% or less.

Water content of the permafrost soil, on the other hand, was found to have significant influences on the sublimation rate. Two measurement locations, close enough to each other to experience similar temperature and humidity conditions, showed a moisture content of approximately 122% and a sublimated thickness of 1.55 in. (3.94 cm). For the same time period, the other site with a moisture content of approximately 67% showed 2.76 in. (7.01 cm) of sublimation.

SUBLIMATION CONTROL

Two approaches to control sublimation have been considered. The first approach is merely a periodic cleaning of the tunnel surface. This approach applies to areas where the particles composing the permafrost are coarse enough not to become suspended in the atmosphere, or to areas where sublimation occurs at a relatively slow rate. In the event that erosion due to sublimation occurs extensively enough to warrant repair, areas can be filled in with a concrete-like frozen soil mixture called permacrete (Swinzow 1965).

The second approach consists of actually retarding the sublimation process. This can be done by two different methods: first, by raising the relative humidity of the air, and second, by inhibiting the moisture in the soil from interacting with the air.

The possibility of raising the relative humidity artificially was

tested by setting up a humidifier of the wet cloth type in the tunnel. As the air passed through the unit its humidity rose from around 60% to nearly 100%. While this method proved to raise the humidity, its feasibility is questionable, as the refrigeration system will either remove this additional moisture or it may become so iced over that it will essentially cease to function. An alternate method of achieving a higher relative humidity would be to alter the refrigeration system so that it condenses less moisture.

The method of retarding the process of sublimation by inhibiting the soil moisture from interacting with the air is discussed below.

TEST INSTALLATIONS

Various materials were used as membranes to test the possibility of stopping or at least significantly inhibiting any interaction between the air and the moisture in the soil. Membranes studied were wood, plastic film, foam insulation, grease, and water. These were observed for a 145-day period, starting on 4 May 1979 and continuing until 25 September 1979.

Sites for the testing of these membranes were selected in the tunnel mainly on the basis of soil grain size. Two stations were erected, one on each side of the adit in an area where the soil was composed mostly of silt-size particles. The water content varied from 67% to 120%, and some organic materials were present. All loose material was removed from the wall to allow the various membranes to be applied to as fresh a surface as possible. By locating the two test stations in the same area (each site area covered about a 6- x 6-ft area of the tunnel wall) similar environments were ensured.

The wood lining consisted of three boards measuring 1 x 6 x 20 in. (2.5 x 15 x 51 cm) (Fig. 3). The boards were nailed directly onto the permafrost surface to cover an 18- x 20-in. (46- x 51-cm) area. Irregularities in the permafrost surface would not allow the wood to fit flat against the surface over the entire area. Along the perimeter the gaps were filled with fiberglass insulation. At the end of the observation period the boards were carefully removed. Several measurements of the thickness of the dust layer behind them were made and averaged. The resulting value was then compared to the average thickness of the dust layer on the unprotected surface surrounding the area covered by the boards. Both surfaces were cleaned of all loose material prior to the application of the wood. The wood lining proved to be about 48% effective in checking sublimation (Table 1).

Polyethylene was used as the test material for the plastic film experiment. Thin boards were laid on the perimeter of the polyethylene and nailed to the permafrost surface, thus making what resembled a picture frame with the polyethylene stretched behind (Fig. 4). Fiberglass insulation was tucked in between the boards and the polyethylene to fill the gaps created by the tunnel wall's uneven surface. The finished covered area measured 12 x 15 in. (30 x 38 cm). At the end of the observation period

Table 1. Data used in calculating the effectiveness value of each of the membranes.

The effectiveness value was calculated by subtracting the value of the average depth of sublimation inside the covered region from the average depth outside the covered region and dividing this value by the average depth outside the region. The headings "IN" and "OUT" used in the table indicate whether the measurement was made inside or outside the region covered by the particular membrane.

	WOOD		POLYETHYLENE		GREASE		PETROLEUM JELLY		ICE 1		ICE 2	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
MEASUREMENTS OF SUBLIMATION AFTER A 145-DAY PERIOD (INCHES)	0.15	0.20	0.02	0.25	0.05	0.15	0.02	0.20	0.02	0.10	0.00	0.15
	0.15	0.25	0.02	0.20	0.10	0.15	0.02	0.15	0.02	0.10	0.00	0.15
	0.10	0.25	0.02	0.25	0.10	0.20	0.02	0.20	0.02	0.05	0.02	0.10
	0.15	0.20	0.02	0.25	0.10	0.15	0.02	0.15	0.04	0.05	0.00	0.10
	0.10	0.20	0.02	0.20	0.05	0.15	0.02	0.15	0.00	0.15	0.00	0.10
	0.15	0.25	0.02	0.20	0.05	0.15	0.02	0.20	0.02	0.15	0.02	0.10
	0.10	0.30	0.02	0.15	0.10	0.20	0.02	0.20	0.00	0.15	0.00	0.10
	0.15	0.25	0.02	0.15	0.10	0.20	0.02	0.15	0.00	0.10	0.00	0.15
	0.10	0.30	0.02	0.15	0.05	0.20	0.02	0.10	0.02	0.10	0.00	0.10
	0.15	0.30	0.02	0.20	0.05	0.15	0.02	0.15	0.00	0.10	0.00	0.10
TOTAL	1.30	2.50	0.20	2.00	0.75	1.70	0.20	1.65	0.14	1.05	0.04	1.15
AVERAGE	0.130	0.250	0.02	0.20	0.075	0.170	0.02	0.165	0.014	0.105	0.004	0.115
EFFECTIVENESS	48%		90%		56%		88%		90%		97%	
AVERAGE EFFECTIVENESS OF WATER											94%	

Figure 3. Wood test lining.

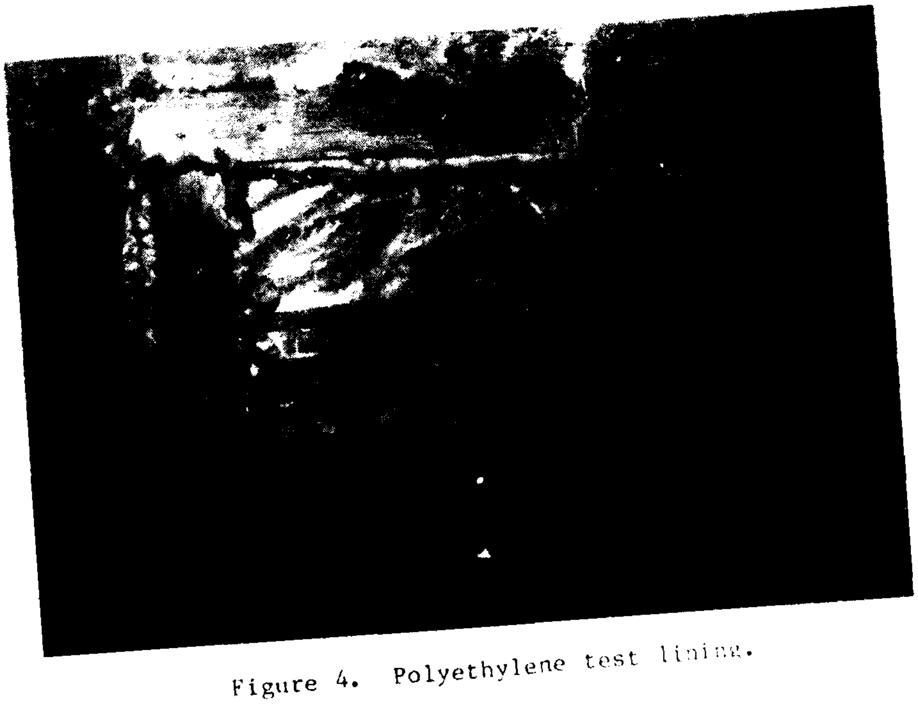

Figure 4. Polyethylene test lining.

one corner of the polyethylene was cut loose and rolled back. It was immediately apparent that there was a definite color difference between the covered and uncovered portions of the permafrost surface (Fig. 5). The area that had been covered was much darker than the surrounding area. Its appearance was close to that of a freshly cut surface. Also noted were small ice crystals (approx. 0.5 mm in diameter) thinly distributed along the back side of the polyethylene. Sublimation measurements were made on the area in the same manner as described for the wood lining. The polyethylene lining proved to be around 90% effective (Table 1) in checking sublimation.

No actual installation was performed for the foam insulation test. Instead, an existing installation of urethane foam installed by CRREL in 1967 was used. This was done to determine the effects of long-term membrane coverage. The CRREL installation consists of a small room lined for the purpose of testing the possibility of heating portions of the tunnel. The room was supposedly never heated enough to melt the surrounding permafrost. A portion of the foam lining was removed from the wall to observe the conditions of the permafrost surface. A layer of well-developed ice crystals measuring an average of 0.5 in. (1.3 cm) thick, formed from sublimation, was adhered to the back of the foam lining (Fig. 6). Immediately behind the ice crystals was a 0.5 in. (1.3 cm) layer of relatively ice-free silt (Fig. 7). Beyond that the permafrost appeared intact. The layer of sublimation material in the areas adjacent to the lined room measured around 4 in. (10 cm) thick.

Two materials were used in testing grease as a liner, automotive grease (Fig. 8) and petroleum jelly. The greases were rubbed onto cleaned portions of the tunnel wall. Within a few days the automotive grease would readily wipe off the wall, and the material directly under it became soft and appeared wet. This effect was apparently due to an additive in the grease that lowers the melting point of water, since a drop of water applied to the grease remained liquid while a drop applied to the petroleum jelly became frozen. The higher viscosity of the petroleum jelly at the tunnel's temperature served to make it much more resistant to abrasion than the grease. Diffusion into the surrounding soil was a characteristic of both the grease (Fig. 9) and the petroleum jelly. However, the petroleum jelly diffused much less than the grease; its boundary expanded by a maximum of 0.5 in. (1.3 cm). Sublimation measurements of these two linings were made by inserting a dissecting needle into the surface until it met some resistance (Fig. 10). These measurements were compared again to those of the surrounding area, yielding an effectiveness of 56% for the grease and 88% for petroleum jelly.

Water was by far the easiest membrane to install. It was simply sprayed onto the wall at low enough rates to limit running and allowed to freeze before the next application (Fig. 8). This spray and freeze process was repeated until a coat of 1 to 2 mm was obtained. The clear coating provided by the water added an optical quality to the wall that revealed a great amount of detail in the permafrost (Fig. 11). The water layer sublimates just as the ice in the soil sublimates (Fig. 12); therefore it re-

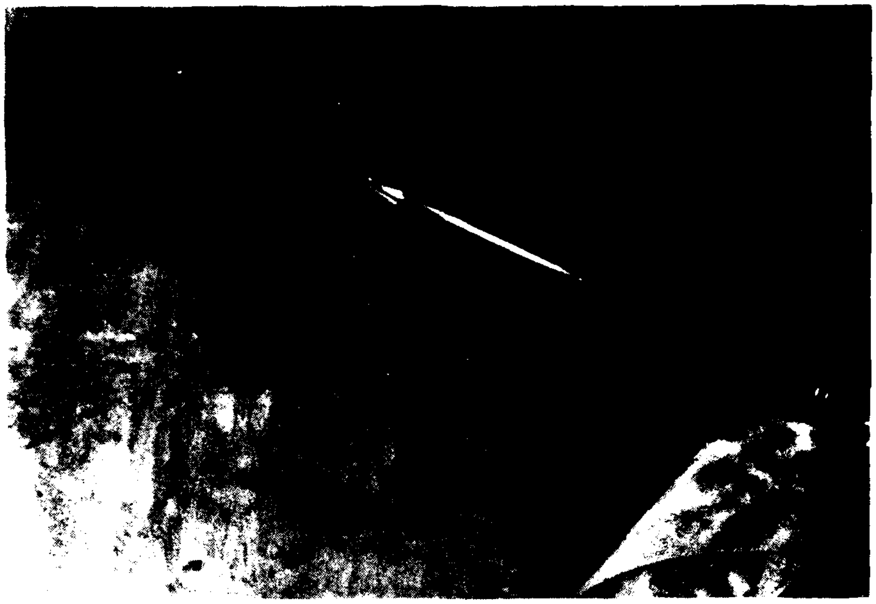

Figure 5. Color difference, original color preserved by polyethylene lining.

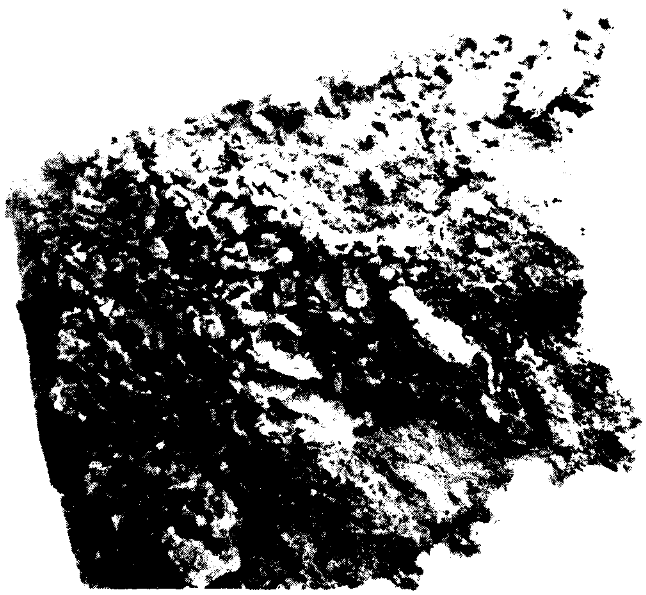

Figure 6. Ice crystal accumulation behind urethane foam.

Figure 7. Ice-free silt behind urethane foam lining.

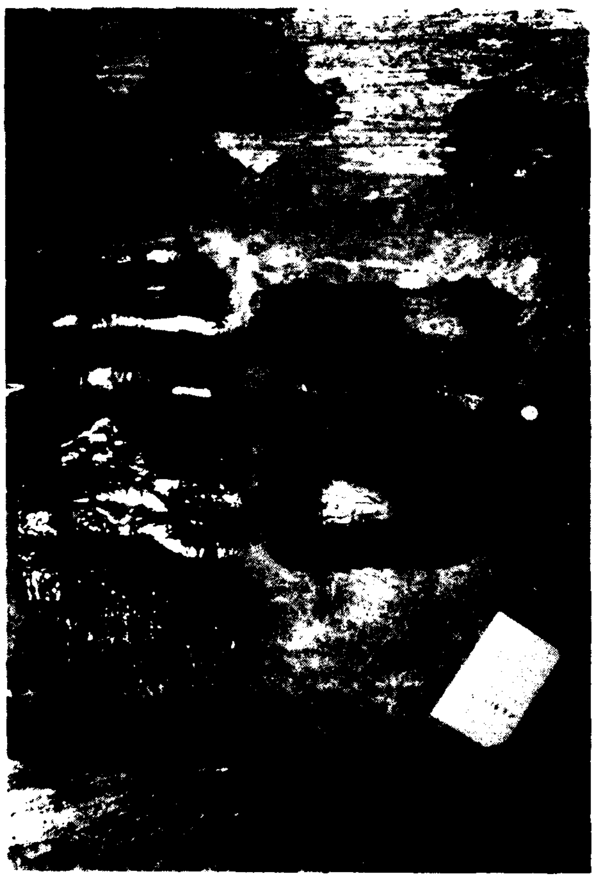

Figure 8. Water test lining 2 and grease test lining.

Figure 9. Diffusion of the grease into the surrounding soil.

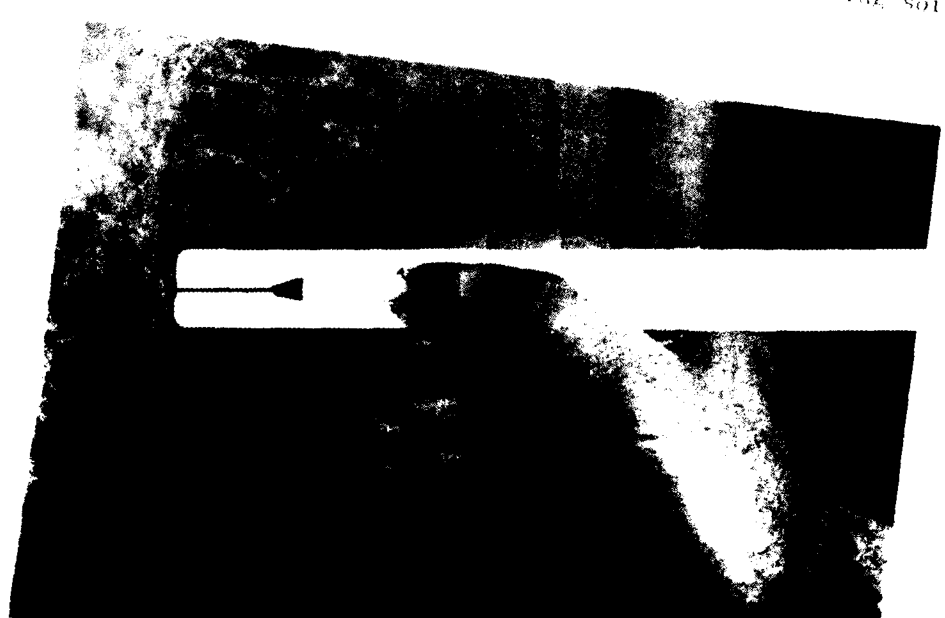

Figure 10. Dissection needle used to measure sublimation.

Figure 11. Details of the ice-rich silt revealed by application of water (ice) lining.

Figure 12. Sublimation of water lining 1.

quires periodic renewal. For the length of the 145-day observation period the surface was recoated three times. At the end of the observation period a series of holes were chipped through the layer to observe any happenings behind it. In most places this probing revealed solid material as expected, but on occasion a layer of relatively ice-free silt was found. For the most part this layer was barely detectable; i.e. it was less than 0.02 in. (0.05 cm) thick, but on one instance a thickness of 0.05 in. (0.13 cm) was found. The thicknesses of this ice-free layer were used to evaluate the effectiveness of the water layer. The result was an effectiveness in preventing sublimation of around 94% (Table 1). No attempt was made to continue to apply water and the ice was allowed to sublimate.

CONCLUSIONS

Overall comparison of the tested membranes shows that the best results occurred with polyethylene, water (ice), and petroleum jelly. The effectiveness of these membranes seems to be due to their ability to actually inhibit moisture migration, rather than simply stop air flow. However, even with the impermeable quality of these membranes, some moisture migration occurred behind them and ice crystals built up behind the membrane, reducing the moisture content in the soil. This is probably due to moisture migration to an area with lower vapor pressure, the tunnel. The formation of ice crystals behind both the polyethylene and the urethane foam offers support to this conclusion.

As for actual use, the water (ice) layer is the most promising due to its effectiveness and ease of application. The polyethylene and petroleum jelly offer slightly less effectiveness. They are considerably more difficult to install but require less long-term maintenance than the water, as the water gradually thins due to sublimation.

It should be pointed out, however, that the spraying of water may not be practical in a warm permafrost tunnel. The heat released upon freezing must be considered. This will be the subject of another study in the near future. Also, this study focused primarily on the dust problem arising from the drying of permafrost silt. A more detailed study on the physics of such soil dehydration should also be addressed as part of future research efforts.

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